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History and Implications of Emerging Transactive Energy Systems

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Global energy goals cannot be met without changes in how we control complex systems

Energy systems

- Potential for substantial efficiencies in end-use systems with new controls
- More data and devices available
- New assets difficult to coordinate
- Existing controls antiquated

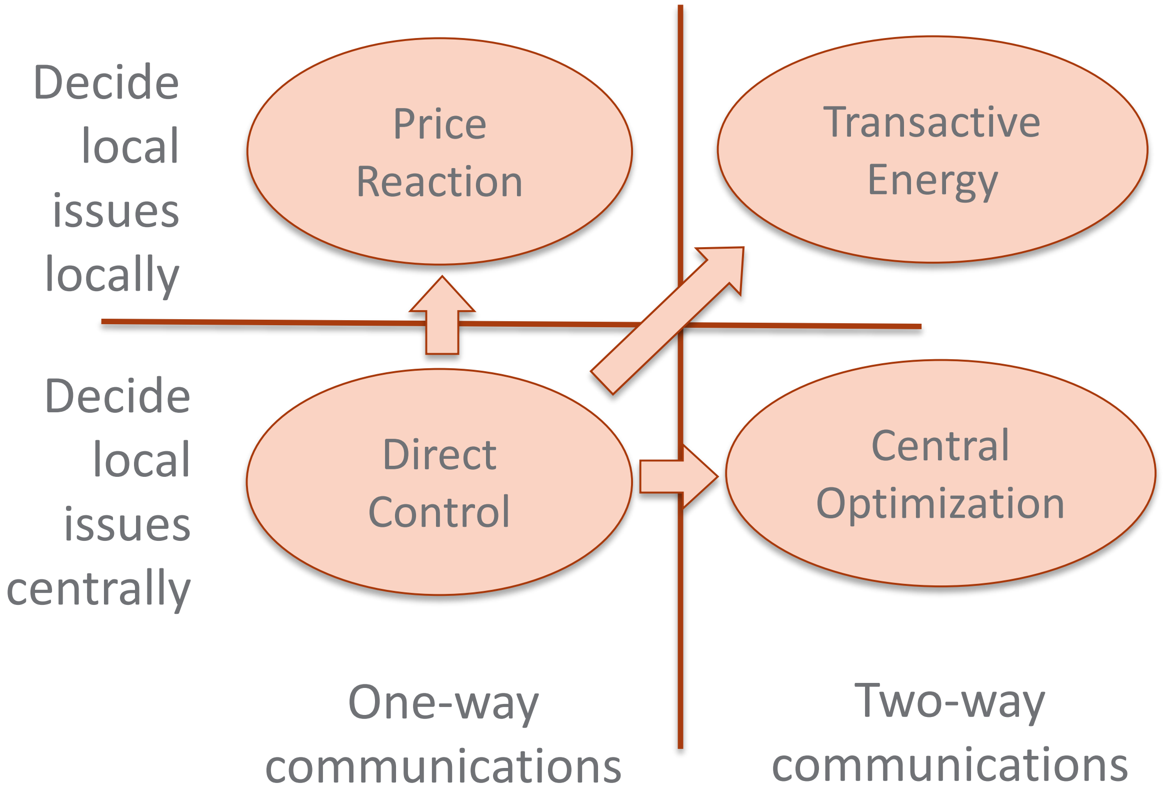
Cyber-physical systems

- Growing “edge” computing resources
- Cloud computing becoming paradigm
- Existing security models challenged

Traditional centralized control approaches are a common weakness

Types of Smart Grid Coordination

- **Direct (Top-Down) Control**
  - Utility switches devices on/off remotely
  - No local information considered
- **Central Control/Optimization**
  - Optimization and control from a central point
  - Relevant local information must be communicated to central point
- **Price Reaction Control**
  - Prices signalled to customers and/or their automated devices
  - No communication of local information
- **Transactive Energy (TE)**
  - Automated devices engage in market interactions
  - Information exchange includes quantity (e.g., power, energy) and price



Slide produced with permission from Dr. Koen Kok, The PowerMatcher Smart Coordination for the Smart Electricity Grid, published by TNO, The Netherlands, 2013. www.tinyurl.com/PowerMatcherBook

What is Transactive Energy?

"system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using ***value*** *as a key operational parameter."*

[*GridWiseTransactive Energy Framework (2015)*]

A Taxonomy of Transactive Systems

Foundation in Economics

Distributed, Constrained Economic Power Flow	Auctions	Bilateral Trades

Foundation in Physics

Distributed, Constrained Economic Power Flow

- Constrained power flow
- DER & resource control
- Dynamic
- Very distributed
- Extensible

Auctions

- Field experience
- DER control
- Dynamic
- Market clearing process
- Intrinsic transport

Bilateral Trades

- Simple
- Intuitive
- Facilitates DER planning
- Clear transactions

Transactive Energy Principles

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Highly automated, coordinated self-optimization	Provide non-discriminatory participation by qualified participants
Transacting parties are accountable for standards of performance	Observable and auditable at interfaces
Maintain system reliability and control while enabling optimal integration distributed energy resources	Scalable, adaptable, and extensible across a number of devices, participants, and geographic extents

Principles: High-level requirements for TE systems that provide an additional point of reference for communicating with stakeholders and identifying common ground within the transactive energy community.

From GridWise Architecture Council's Transactive Energy Framework
http://www.gridwiseac.org/about/transactive_energy.aspx

Some Transactive Energy Demonstrations

Olympic Peninsula demo, ca. 2006-07

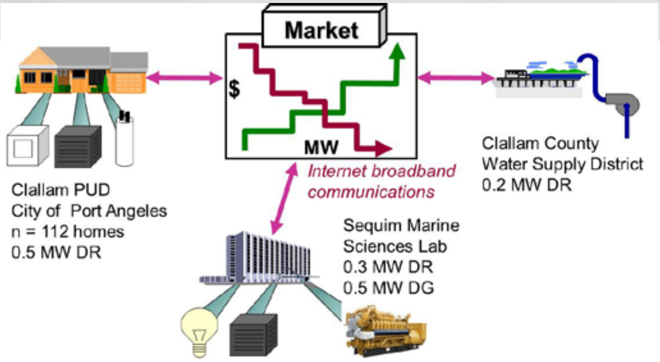
- Established viability of transactive, decision-making to coordinate to achieve multiple objectives
  - Peak load, distribution constraints, wholesale prices
  - Residential, commercial, & municipal water pumping loads, distributed generation

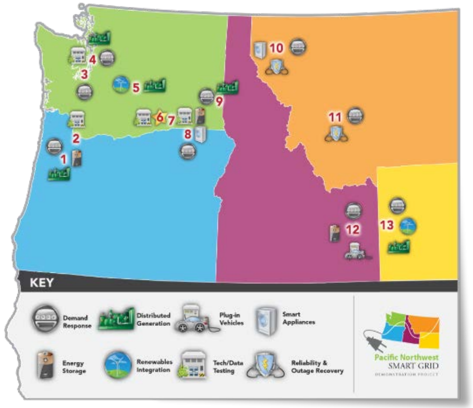
AEP Ohio gridSMART® demo, ca. 2010-2014

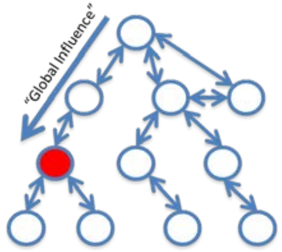
- PUC-approved RTP tariff developed
  - Provides dynamic, real-time incentive to respond
  - Reflects real-time prices in PJM energy market
  - Manages AEP T&D constraints and peak load

Pacific NW Smart Grid demo, ca. 2010-2015

- Key advancements made by PNWSGD
  - Wind balancing
  - Developed look ahead signals
  - Formalized standardized definition of transactive node, test rig, etc.
  - Showed how "old school" approaches (e.g. direct load control) can be integrated with a transactive schema







Overview of a Transactive Auction Mechanism

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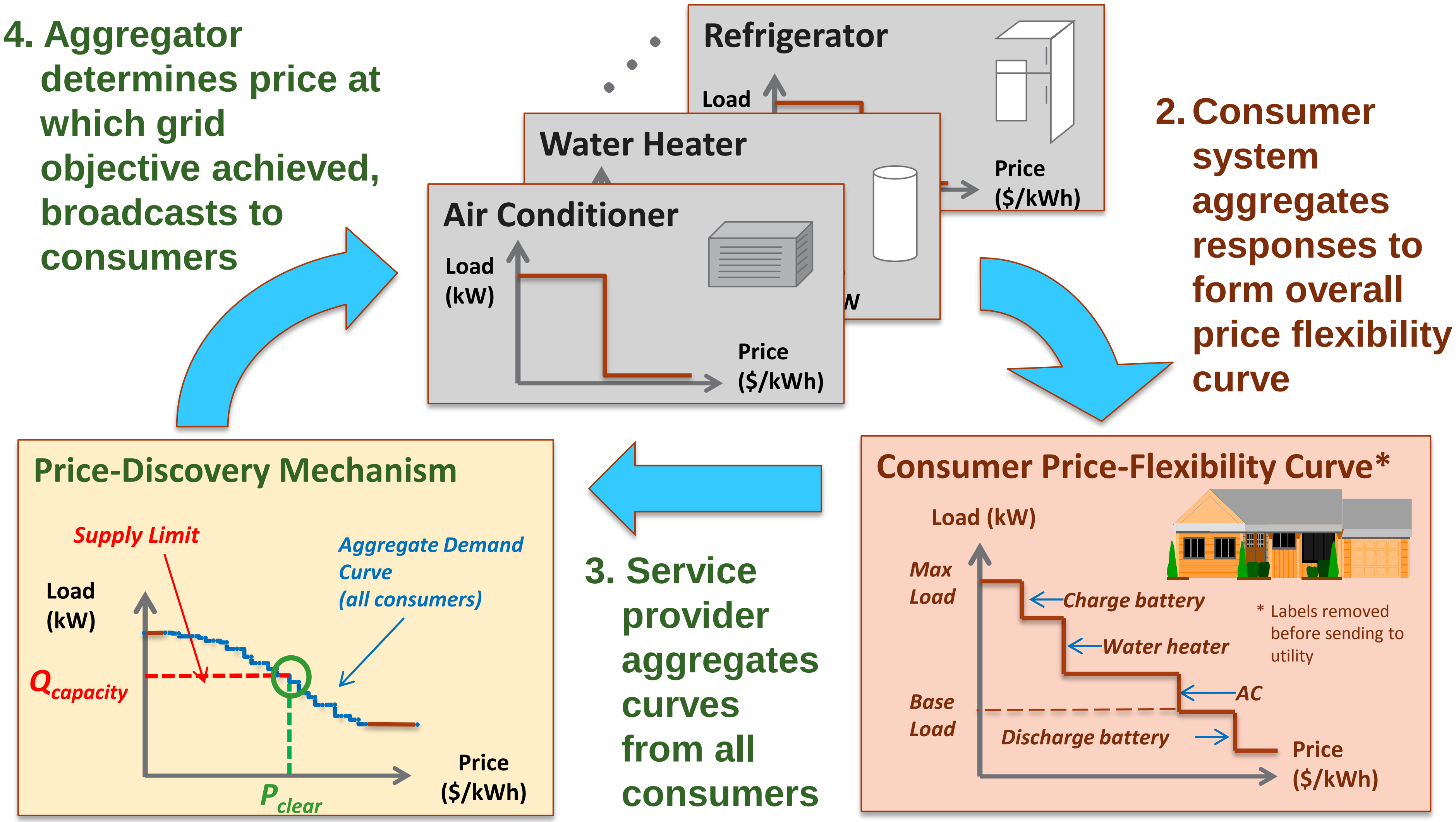
1. Automated, price-responsive device controls express consumer's flexibility (based on current needs)
2. Consumer system aggregates responses to form overall price flexibility curve
3. Service provider aggregates curves from all consumers
4. Aggregator determines price at which grid objective achieved, broadcasts to consumers



Transactive Thermostat Control

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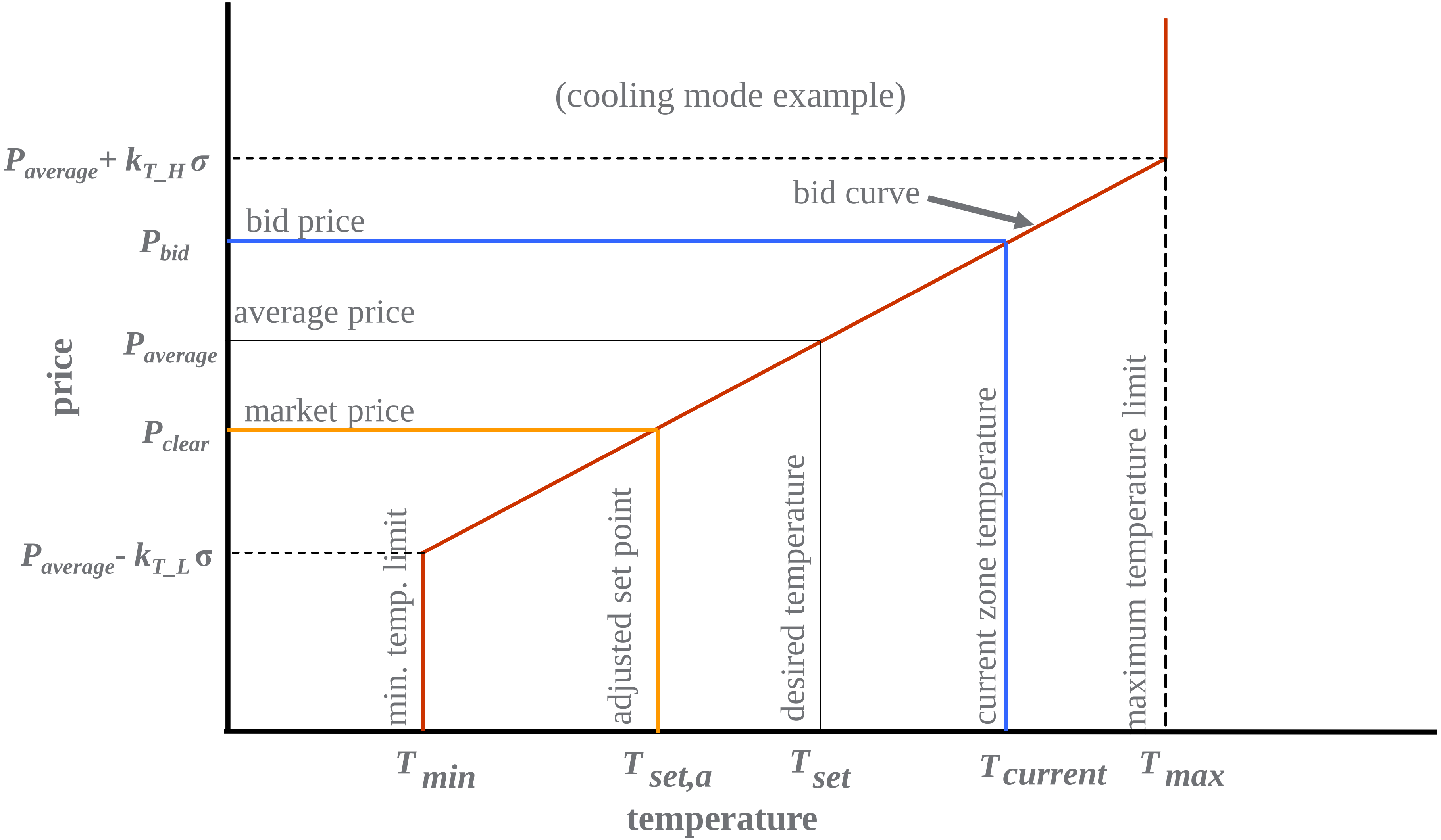
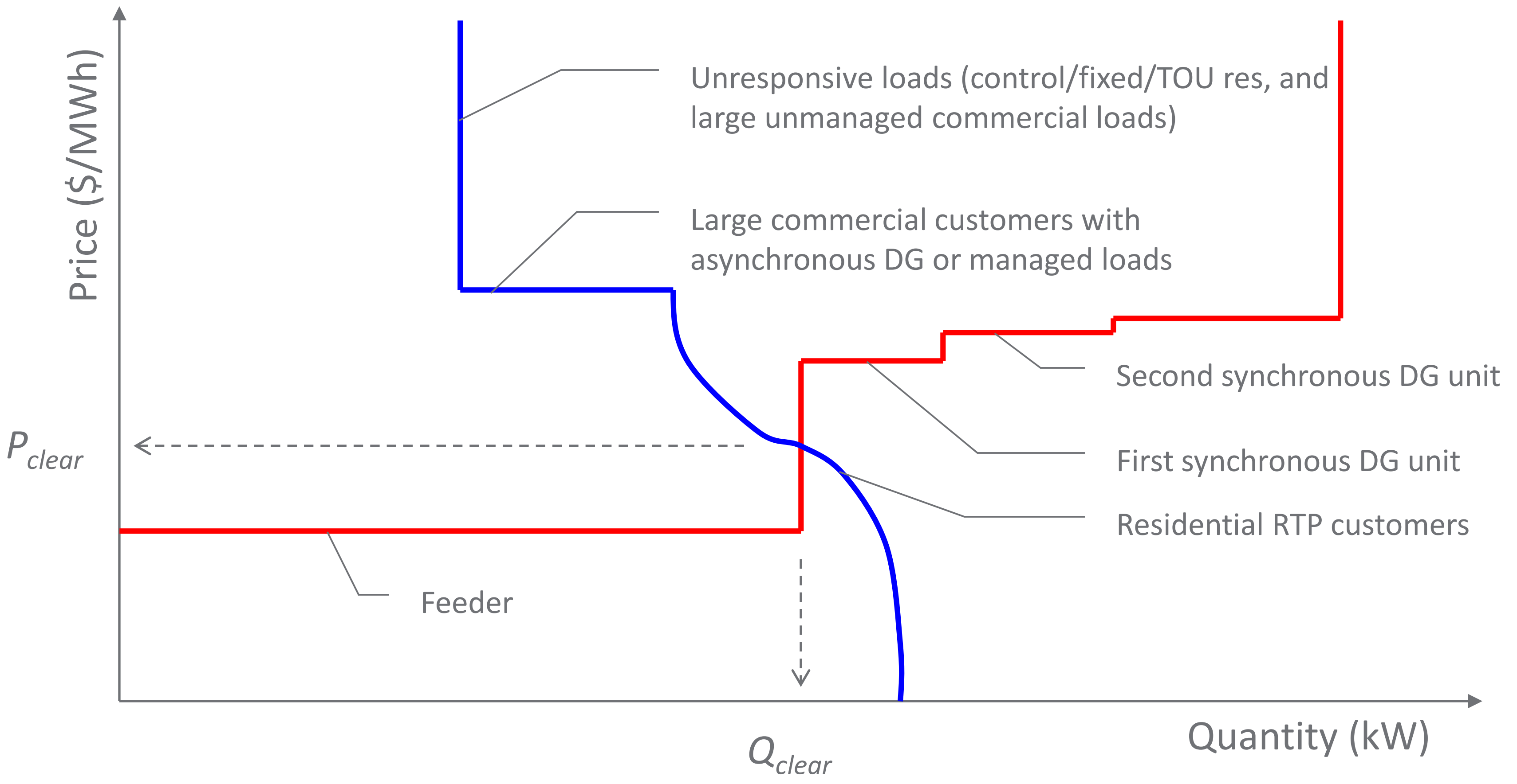


Price-Based Distribution Dispatch



Pacific Northwest Smart Grid Demonstration (PNWSGD) Project

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What:

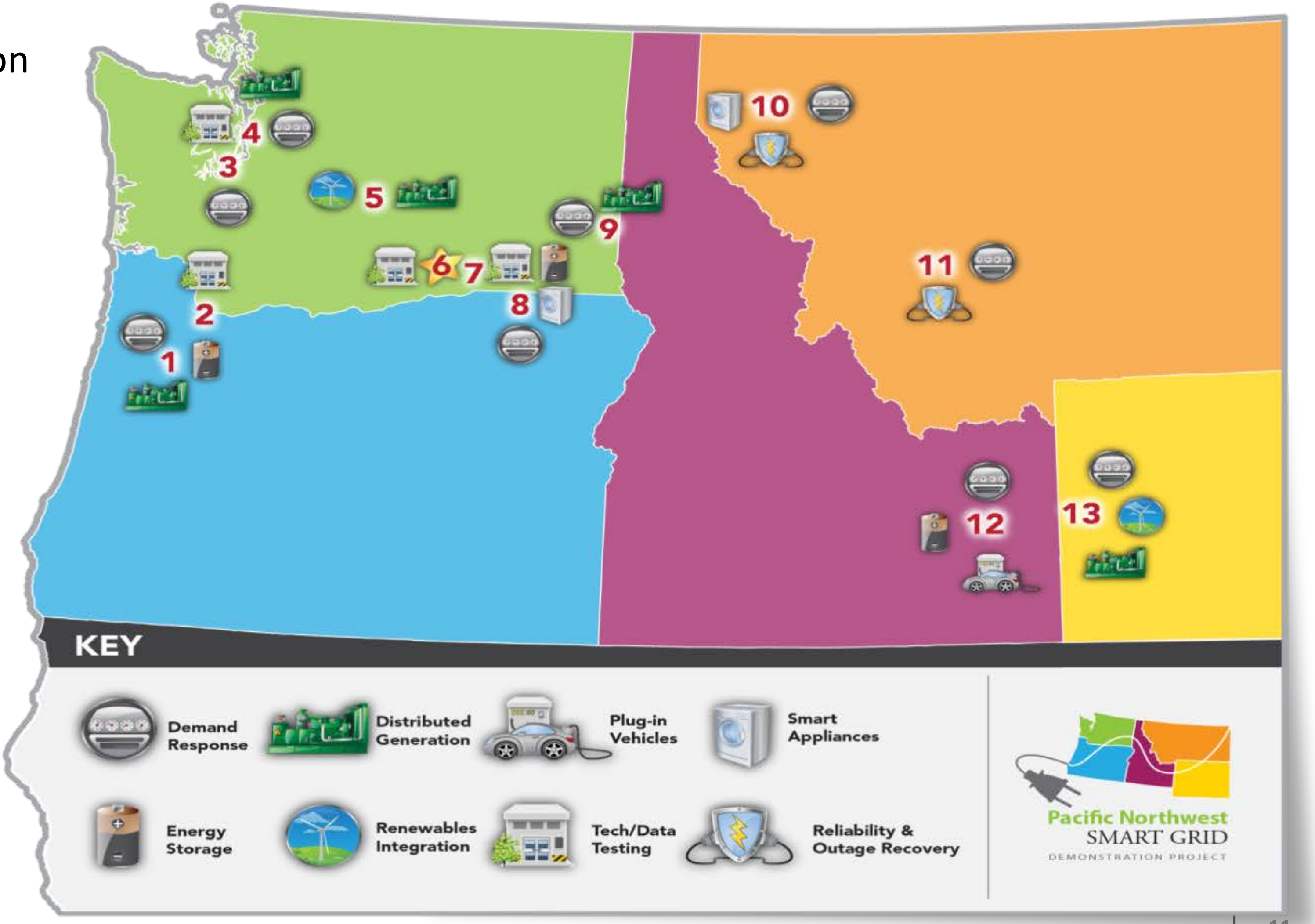
- $178M, ARRA-funded, 5-year demonstration
- 60,000 metered customers in 5 states

Why:

- Develop communications and control infrastructure using incentive signals to engage responsive assets
- Quantify costs and benefits
- Contribute to standards development
- Facilitate integration of wind and other renewables

Who:

Led by Battelle and partners including BPA, 11 utilities,
2 universities, and
5 vendors



PNWSGD Demonstration Region

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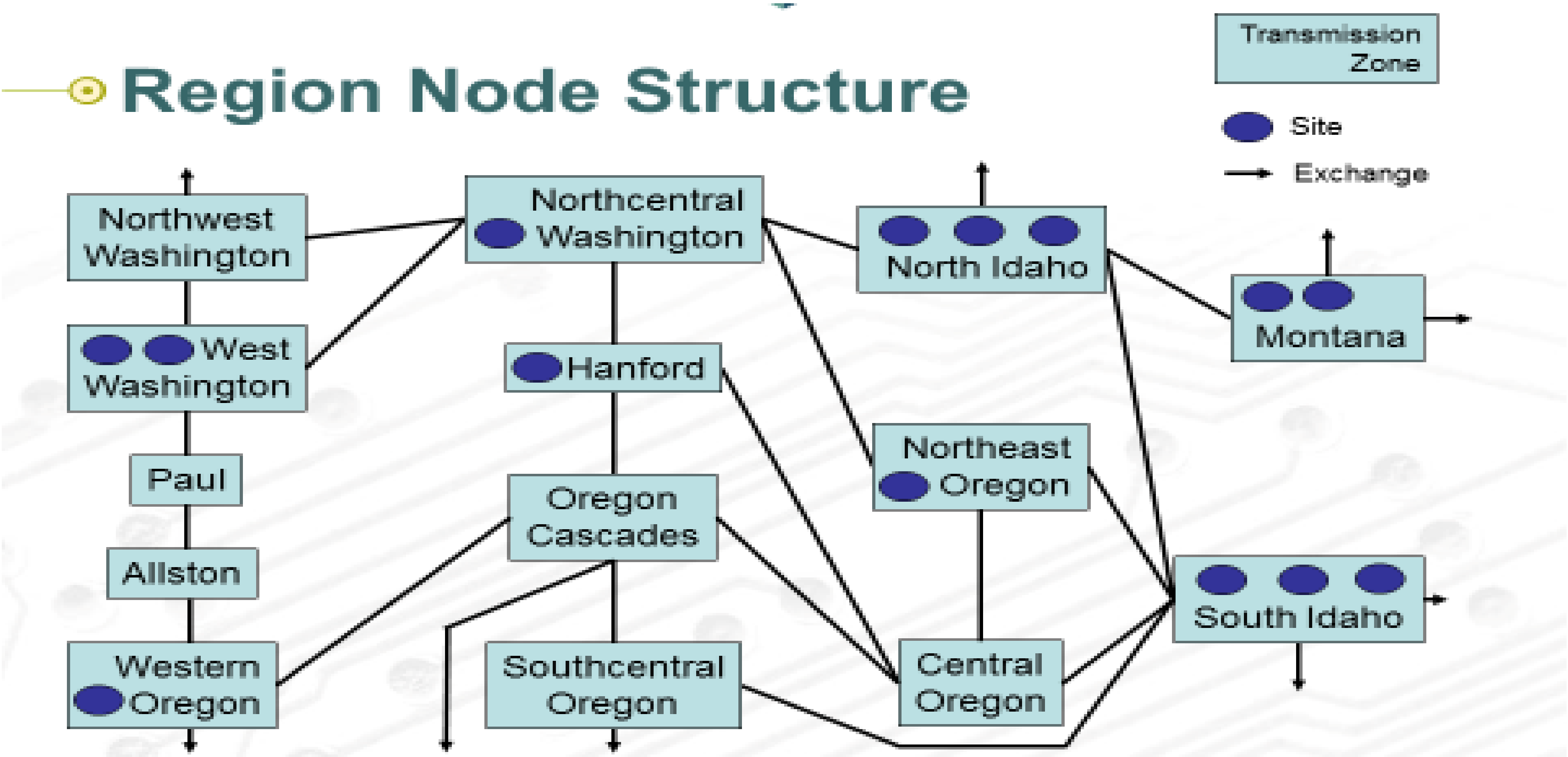


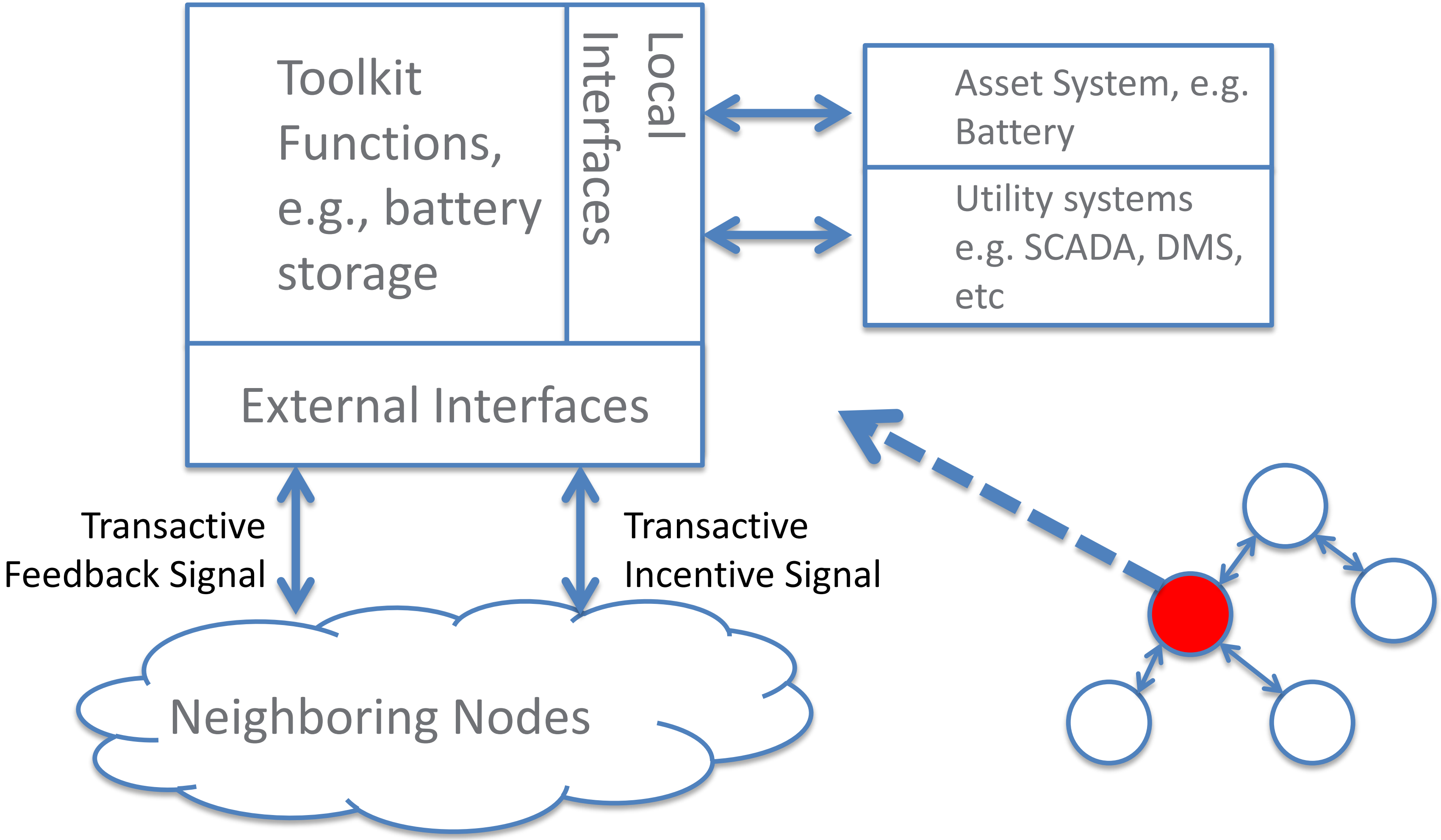
Basic Responsibilities of Nodes in the PNWSGD

Cost ($/MW) = function (Resources (MW))

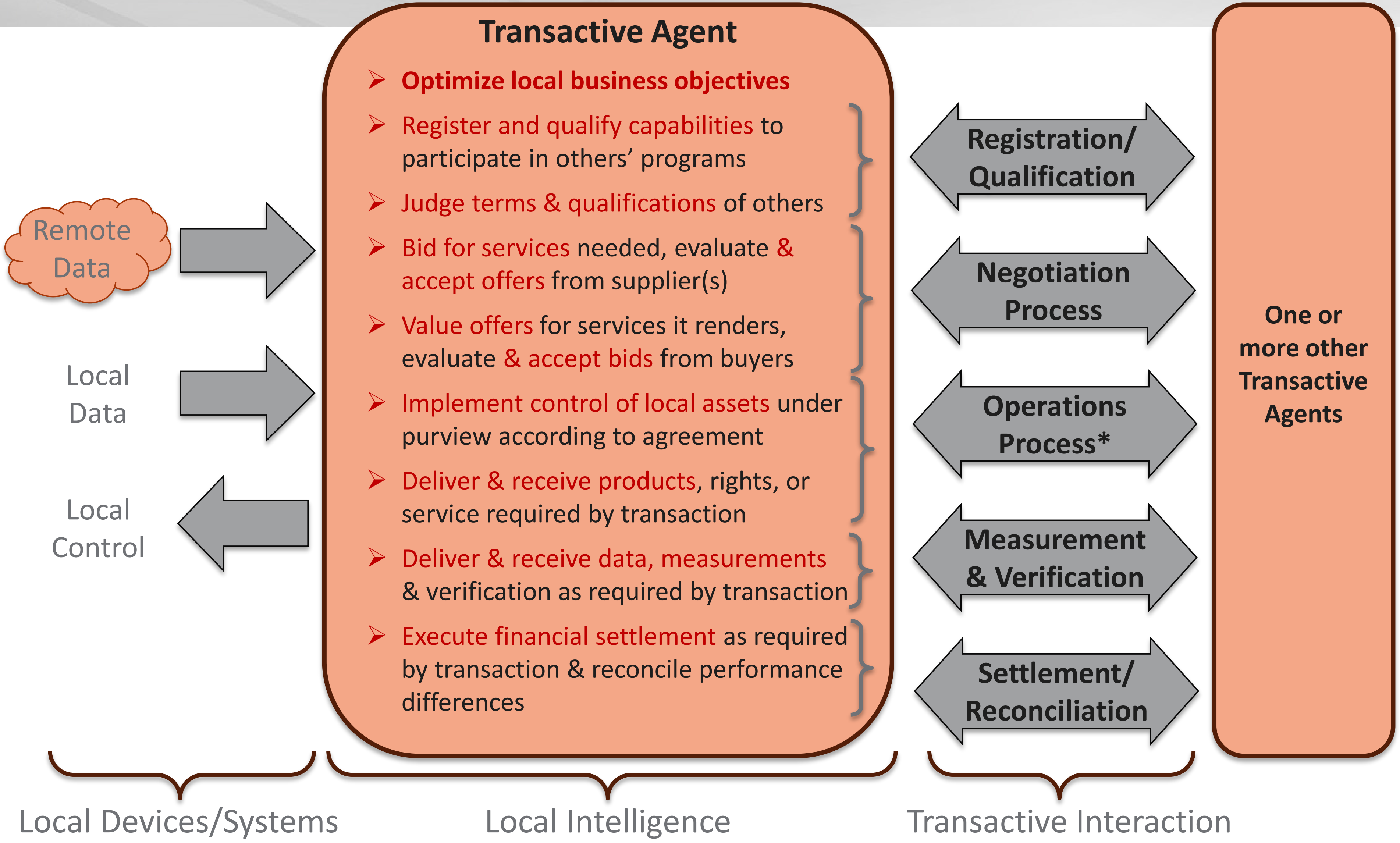
function (Cost ($/MW)) = Load (MW)

This exchange occurs at every “node” into a horizon of future time intervals.

Functional Elements of a Node



Transactive Interaction Model



* E.g., operations signals or e-product exchange

Grid Friendly™ Appliance (GFA) Demonstration (Autonomous Devices)

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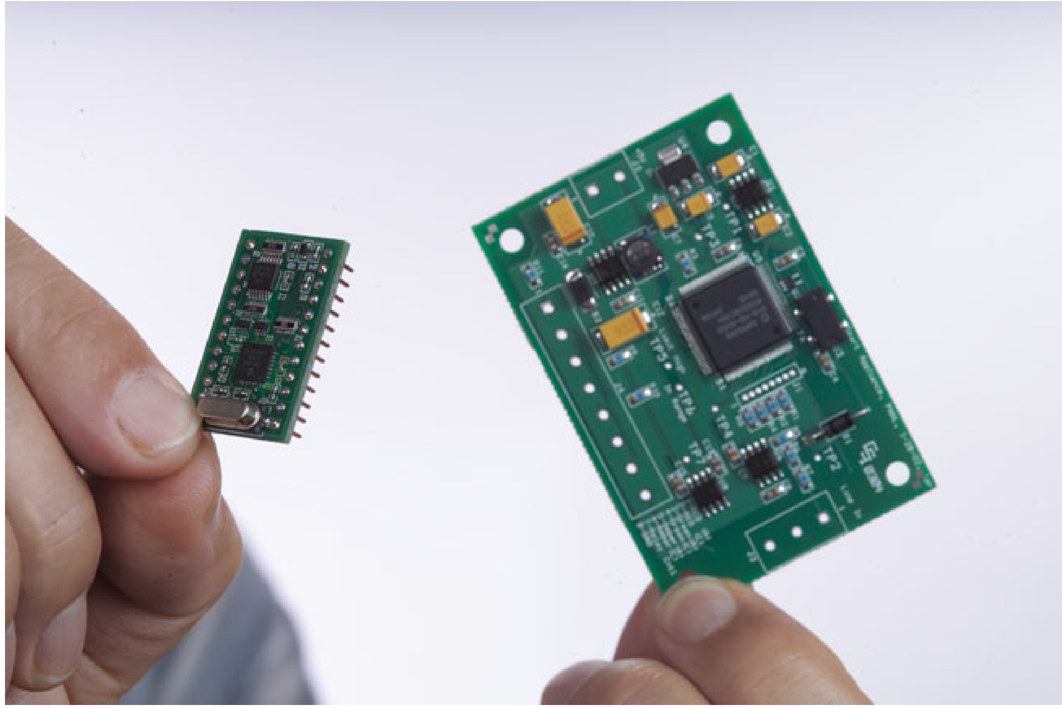
- Autonomous GFA under frequency curtailment response to 200 appliances in 150 residences
  - 150 Whirlpool/Sears dryers
  - 50 water heaters
- Assess performance through correlation with frequency events
  - Event log & load data collection (Invensys)
- Assess consumer acceptance – Whirlpool post-survey



"When the inevitable occurs … people get stuck in elevators and high-value uses of power are shut off along with all the lowest priority uses of energy. It's the meat-ax approach to interrupting power flows."

Dr. Vernon Smith, 2002 Nobel prize Winner, Economics

Small Appliances?

This is the world's first Grid Friendly™ frequency-responsive coffee maker. Which appliances are too small to participate in grid reliability services?

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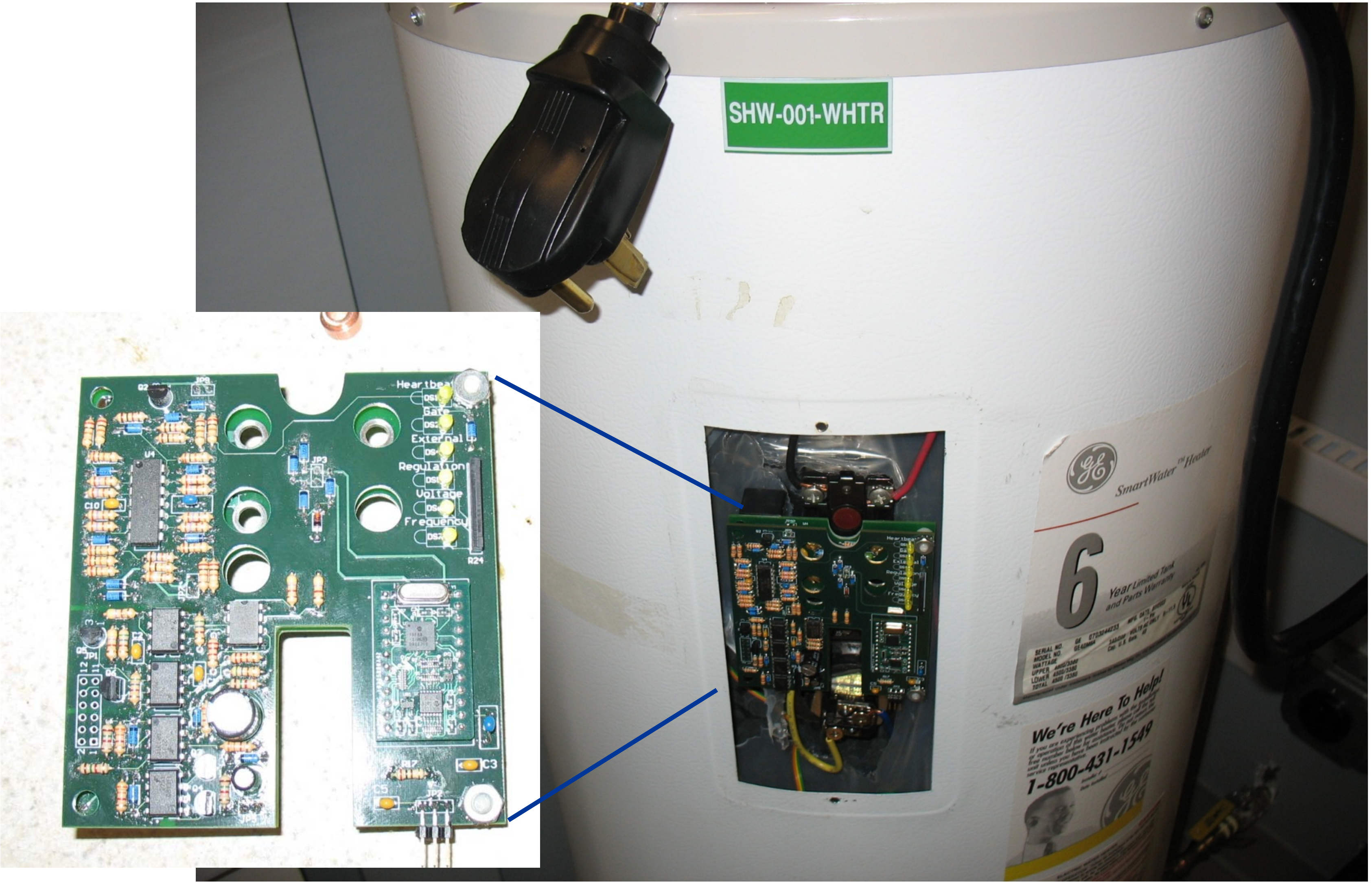
Grid Friendly Water Heater Controller



Autonomous Frequency Regulation

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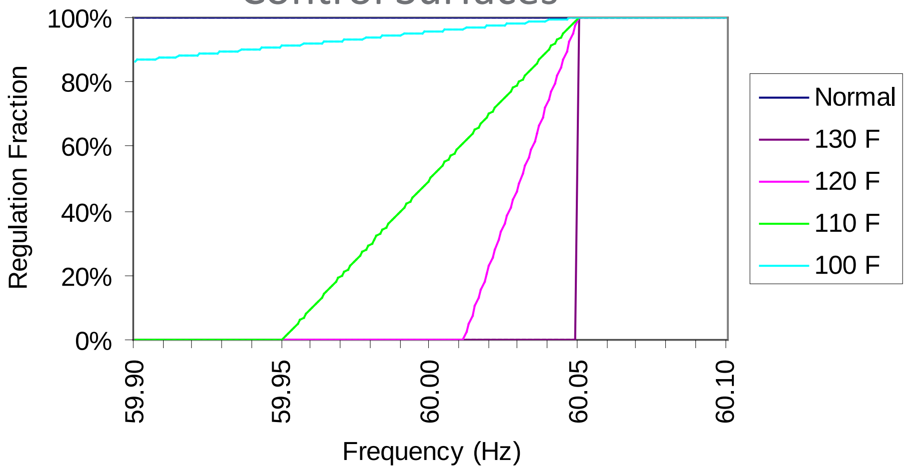
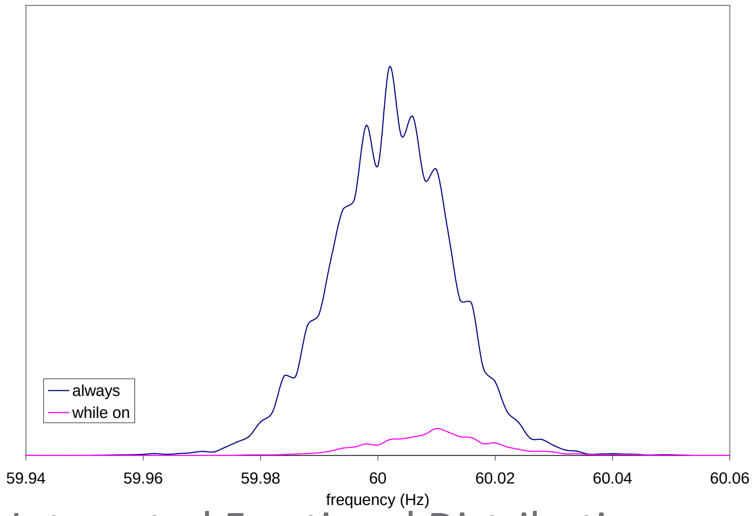
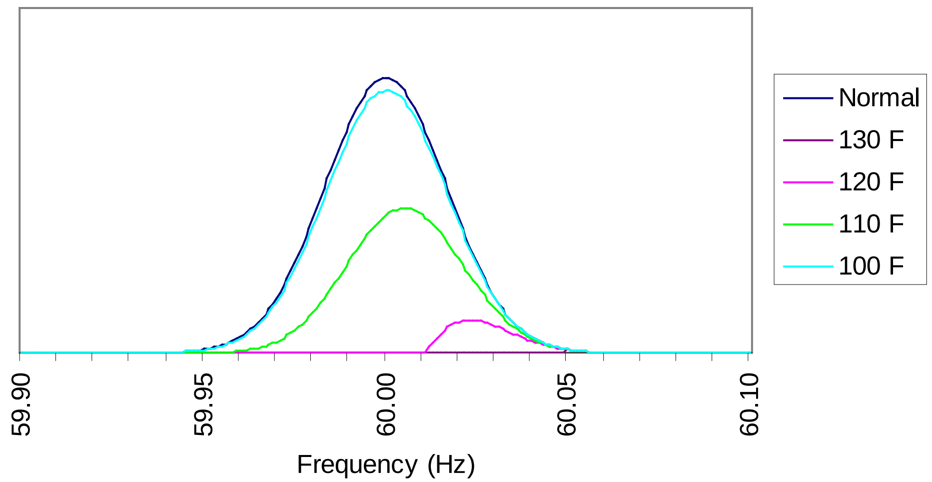
Control Surfaces



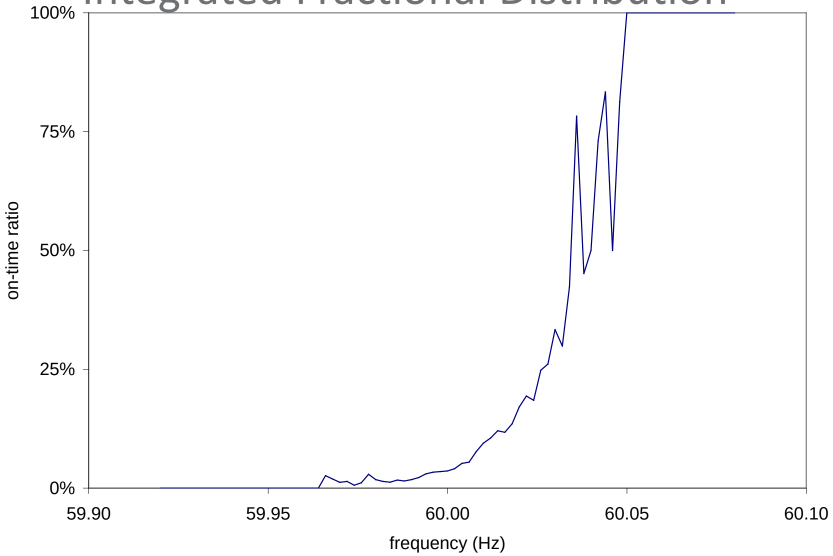
Measured Frequency Distributions



Control Frequency Distribution Envelopes



Integrated Fractional Distribution



Implications for Power Electronics

- Devices are getting smarter → Controls
- System is getting more collaborative → Communications
- Systems are more dynamic → Resiliency
- Control is more distributed → Flexibility
- Rethink existing paradigms (DC power, microgrids) → Innovation
- Power electronic systems are being asked to do more → Opportunity

Acknowledgement & Disclaimer

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